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Throughput-Enhanced Communication Approach for Subscriber Stations in IEEE 802.16 Point-to-Multipoint Networks

Chung-Hsien Hsu and Kai-Ten Feng

*Department of Electrical Engineering, National Chiao Tung University
Taiwan, R.O.C.*

1. Introduction

The IEEE 802.16 standard for wireless metropolitan area networks (WMANs) is designed to satisfy various demands for high capacity, high data rate, and advanced multimedia services (Abichar et al., 2006). The medium access control (MAC) layer of IEEE 802.16 networks supports both point-to-multipoint (PMP) and mesh modes for packet transmission (IEEE Std. 802.16-2004, 2004). Based on the application requirements, it is suggested in the standard that only one of the modes can be exploited by the network components within the considered time intervals, and the PMP mode is considered the well-adopted one. In the PMP mode, packet transmission is coordinated by a base station (BS) which is responsible for controlling the communication with multiple subscriber stations (SSs) in both downlink (DL) and uplink (UL) directions. All the traffic within an IEEE 802.16 PMP network can be categorized into two types, including inter-cell traffic and intra-cell traffic. For the inter-cell traffic, the source-destination pair of each traffic flow are located in different cells. On the other hand, the intra-cell traffic is defined if they are situated within the same cell. The inefficiency within the PMP mode occurs while two SSs are intended to conduct packet transmission, i.e., the intra-cell traffic between the SSs. It is required for the data packets between the SSs to be forwarded by the BS even though the SSs are adjacent with each others. Due to the packet rerouting process, the communication bandwidth is wasted which consequently increases the packet-rerouting delay.

In order to alleviate the drawbacks resulted from the indirect transmission, a directly communicable mechanism between SSs should be considered in IEEE 802.16 networks. Several direct communication approaches have been proposed for different types of networks. The direct-link setup (DLS) protocol is standardized in the IEEE 802.11z draft standard to support direct communication between two SSs in wireless local networks (IEEE P802.11zTM/D5.0, 2009). However, the DLS protocol is designed as a contention-based mechanism, which does not guarantee the access of direct link setup and data exchanges between two SSs. The dynamic slot assignment (DSA) scheme for Bluetooth networks is proposed in (Zhang et al., 2002) and (Cordeiro et al., 2003), which is primarily implemented based on the characteristics of the Bluetooth standard. Since frame structures and medium access mechanisms are different among these wireless communication technologies, both the DLS protocol and DSA scheme cannot be directly applied to IEEE 802.16 networks.

In this book chapter, a point-to-point direct communication (PDC) approach is proposed for achieving direct transmission between two SSs. The PDC approach is designed as a flexible and contention-free scheme especially for time division duplexing based IEEE 802.16 PMP networks. The BS is coordinating and arranging specific time intervals for the two SSs that are actively involved in packet transmission. Both the relative locations and channel conditions among the BS and SSs are utilized as constraints for determining if the direct communication should be adopted. The advantage of exploiting the PDC approach is that both the required bandwidth for packet transmission and packet-rerouting delay for intra-cell traffic can be significantly reduced. The effectiveness of the proposed PDC approach can be observed via the simulation results, which demonstrate that the PDC approach outperforms the conventional IEEE 802.16 transmission mechanism in terms of user throughput.

The remainder of this book chapter is organized as follows. Section 2 briefly reviews the MAC frame structure and packet transmission mechanism in IEEE 802.16 PMP networks. The proposed PDC approach, consisting of management structures, an admission control scheme, and direct communication procedures, is described in Section 3. The performance of the PDC approach is evaluated in Section 4. Section 5 draws the conclusions.

2. IEEE 802.16 PMP Networks

The PMP mode is considered the well-adopted network configuration in IEEE 802.16 networks wherein the BS is responsible for controlling all the communication among SSs. Two duplexing techniques are supported for the SSs to share common channels, i.e., time division duplexing (TDD) and frequency division duplexing. The MAC protocol is structured to support multiple physical (PHY) layer specifications in the IEEE 802.16 standard. In this book chapter, the WirelessMAN-OFDM PHY, utilizing the orthogonal frequency division multiplexing (OFDM), with TDD mode is exploited for the design of the proposed PDC approach. Both the frame structure and packet transmission mechanism of IEEE 802.16 PMP networks are described in the following subsections.

2.1 Frame Structure

Fig. 1 illustrates the schematic diagram of the IEEE 802.16 PMP OFDM frame structure with TDD mode. It can be observed that each frame consists of a DL subframe and a UL subframe. The DL subframe contains only one DL PHY protocol data unit (PDU), which starts with a long preamble for PHY synchronization. The preamble is followed by a frame control header (FCH) burst and several DL bursts. A DL frame prefix (DLFP), which is contained in the FCH, specifies the burst profile and length for the first DL burst (at most four) via the information element (IE). It is noted that each DL burst may contain an optional preamble and more than one MAC PDUs that are destined for the same or different SSs. The first MAC PDU followed by the FCH is the DL-MAP message, which employs DL-MAP IEs to describe the remaining DL bursts. The DL-MAP message can be excluded in the case that the DL subframe consists of less than five bursts; nevertheless, it must still be sent out periodically to maintain synchronization. A UL-MAP message immediately following the DL-MAP message denotes the usage of UL bursts via UL-MAP IEs. An interval usage code, corresponding to a burst profile, describes a set of transmission parameters, e.g., the modulation and coding type, and the forward error correction type. The DL interval usage code (DIUC) and UL interval usage code (UIUC) are specified in the DL channel descriptor (DCD) and UL channel descriptor (UCD) messages respectively. The BS broadcasts both the DCD and UCD messages periodically to define the characteristics of the DL and UL physical channels respectively.

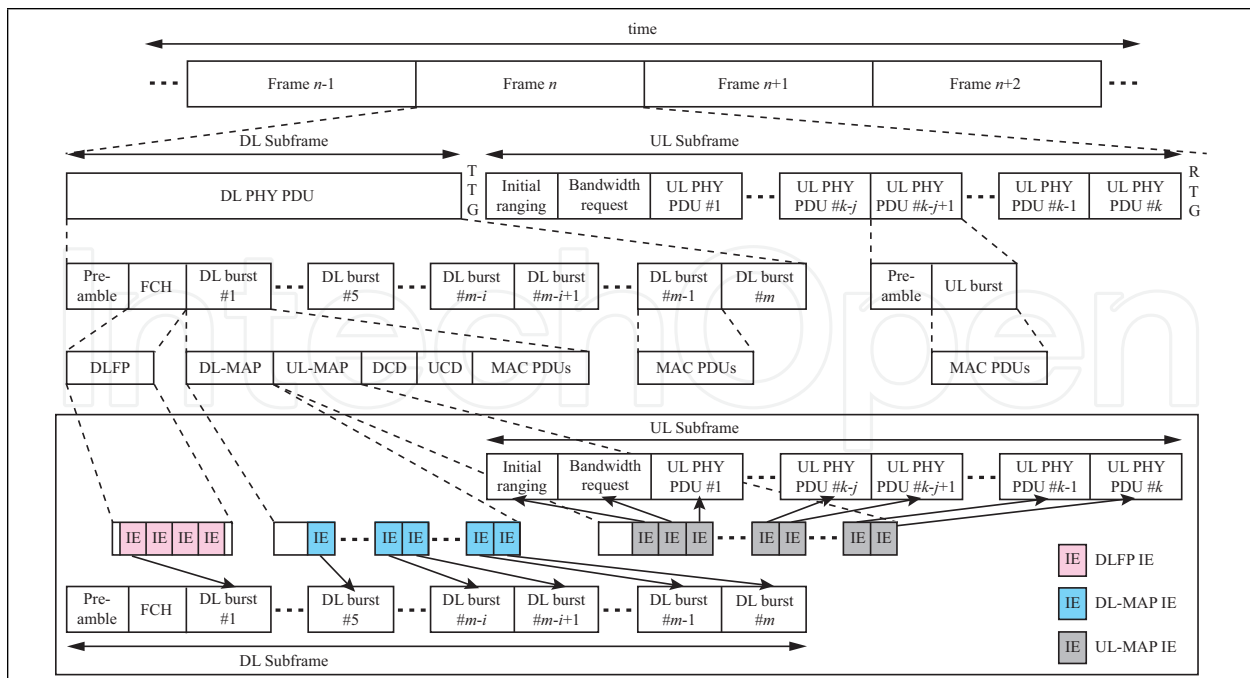


Fig. 1. Schematic diagram of IEEE 802.16 PMP OFDM frame structure with TDD mode.

On the other hand, as can be seen from Fig. 1, the UL subframe starts with the contention intervals that are specified for both initial ranging and bandwidth request. It is noted that more than one UL PHY PDU can be transmitted after the contention intervals. Each UL PHY PDU consists of a short preamble and a UL burst, where the UL burst transports the MAC PDUs for each specific SS. Moreover, a transmit-to-receive transition gap (TTG) and a receive-to-transmit transition gap (RTG) are inserted in between the DL and the UL subframes and at the end of each frame respectively. These two gaps provide the required time for the BS to switch from the transmit to receive mode and vice versa.

2.2 Packet Transmission Mechanism

A connection in IEEE 802.16 PMP networks is defined as a unidirectional mapping between the BS and an MS, which is identified by a 16-bit connection identifier (CID). Two kinds of connections, including management connections and transport connections, are defined in the IEEE 802.16 standard. The management connections are utilized for delivering MAC management messages; while the transport connections are employed to transmit user data. During the initial ranging of a SS, a pair of UL and DL basic connections are established, which belong to a type of the management connections. It is noted that a single Basic CID is assigned to a pair of UL and DL basic connections, which is served as the identification number for the corresponding SS. Thus the SS uses the individual transport CID to request bandwidth for each transport connection while the BS arranges the accumulated transmission opportunity by addressing the Basic CID of the SS.

An exemplified network topology that consists of one BS and two neighboring SSs is shown in Fig. 2. Two types of traffic exist in the network: inter-cell traffic and intra-cell traffic. For the inter-cell traffic, the source and the destination for each traffic flow are located in different cells, e.g., the traffic flow of SS_2 for accessing the Internet. On the other hand, the intra-cell traffic is defined while the source and destination are situated within the same cell network,

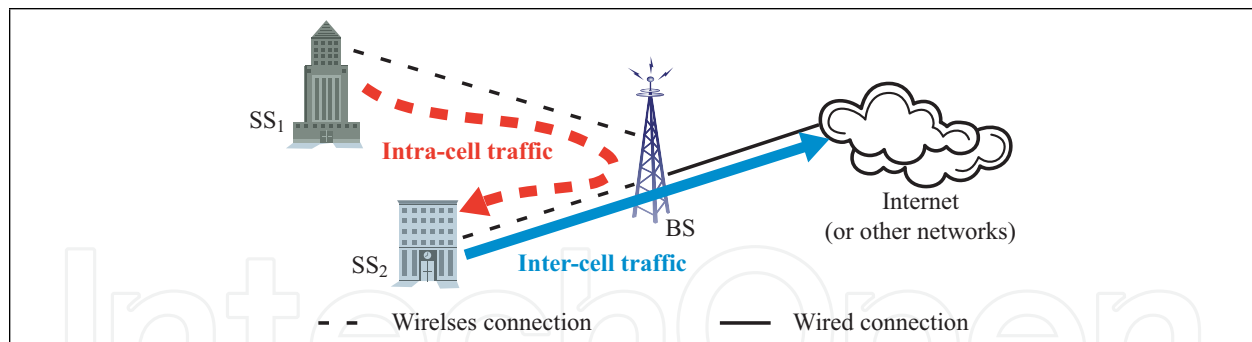


Fig. 2. Example of IEEE 802.16 PMP network topology.

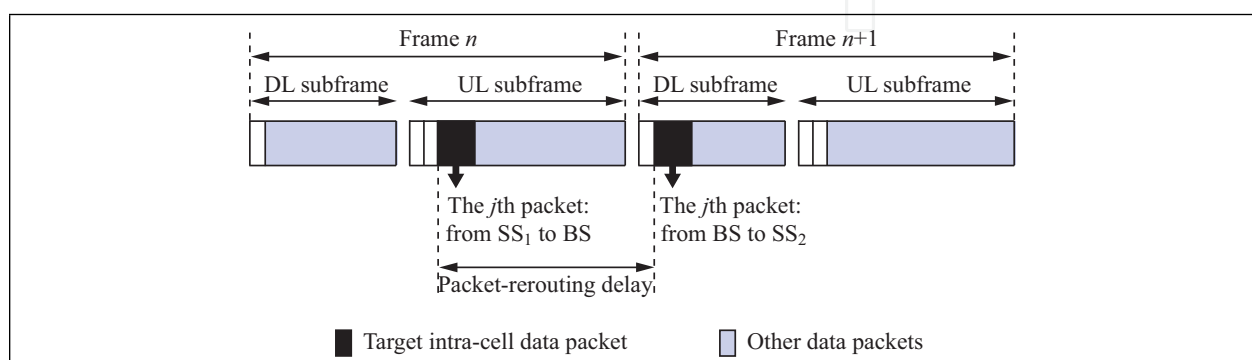


Fig. 3. Schematic diagram of IEEE 802.16 packet transmission mechanism in time sequence.

such as the traffic flow between SS_1 and SS_2 in Fig. 2. Considering the scenario that SS_1 intends to communicate with its neighboring station SS_2 , two transport connections are required to be established via the service flow management mechanism for the intra-cell traffic, i.e., the UL transport connection from SS_1 to the BS and the DL transport connection from the BS to SS_2 . Fig. 3 illustrates the conventional transmission mechanism of IEEE 802.16 PMP networks in time sequence. In the most ideal case, the j th intra-cell packet, transmitted from SS_1 to the BS in the n th frame, will be forwarded to SS_2 in the $(n+1)$ th frame by the BS. The rerouting process apparently requires twice of communication bandwidth for achieving the intra-cell packet transmission, which consequently increases control overhead by duplicating the corresponding data packet. Moreover, the delay time for packet-rerouting can be more than one half of a frame duration while the packet transmission from the BS to SS_2 is postponed to a latter DL subframe.

3. Point-to-point Direct Communication (PDC) Approach

The objective of the proposed PDC approach is to provide a directly communicable mechanism for SSs within IEEE 802.16 PMP networks such that both the communication bandwidth and packet-rerouting delay of intra-cell traffic are reduced. The PDC approach is designed as a flexible and contention-free scheme wherein the establishment of direct link is conducted along with packet transmission. Based on the channel conditions among the BS and SSs, the BS coordinates and arranges specific time intervals for the two SSs that are actively involved in packet transmission. It is worthwhile to mention that the PDC approach is carried out after the establishment of the original transmission path, which is compatible and can be directly integrated with the existing protocols defined in the IEEE 802.16 standard. In the following

subsections, the proposed architecture and management structures will be described in Subsection 3.1; while an admission control scheme for direct link establishment is explained in Subsection 3.2. The direct communication procedures of the PDC approach are given in Subsection 3.3.

3.1 Architecture and Management Structure

For the purpose of providing time intervals for direct transmission between SSs, a point-to-point direct link (PDL) subframe is proposed in the PDC approach. A PDL subframe that consists of one or more PDL PHY PDUs is designed as a subset of a DL or UL subframe. Each PDL PHY PDU starts with a short preamble followed by a PDL burst, which is designed to transport the MAC PDUs for each specific SS. Furthermore, in order to be compatible with the existing IEEE 802.16 standard, three categories of management structures are proposed, which are detailed as follows:

- **DL-PDL IE and UL-PDL IE.** The proposed DL-PDL IE and UL-PDL IE are designed to depict burst profiles and lengths of their corresponding PDLs in the DL and UL subframes respectively. The DL-PDL IE is a new type of the extended DIUC dependent IE within the OFDM DL-MAP IE; while the UL-PDL IE is a new type of the UL extended IE that is contained in the OFDM UL-MAP IE. It is noted that the formats of both the proposed DL-PDL IE and UL-PDL IE are designed to conform to the formats of the DL-MAP dummy IE and UL-MAP dummy IE, specified in the IEEE 802.16 standard, respectively.
- **PDL Subheader.** The PDL subheader is designed for implementing the request, response, announcement, and termination of the direct communication. It is a new type of per-PDU subheader, which can be inserted in the MAC PDUs immediately followed by the generic MAC header in both the DL and UL directions. For different purposes, the DL subheader carries various types of information, including MAC addresses, CIDs, and location information.
- **PBPC-REQ and PBPC-REP Messages.** In the IEEE 802.16 standard, the adaptive modulation and coding (AMC) is exploited as the link adaptation technique to improve the network performance on time-varying channels. The BS selects an adequate modulation and coding scheme (MCS) for a SS based on the reported signal-to-interference and noise ratio (SINR) value. Moreover, the BS permits the changes in MCS that are suggested by the SS via the burst profile change request message. Similarly, both the proposed PDL burst profile change request (PBPC-REQ) and response (PBPC-REP) messages are designed to change the MCS applied in a direct link. The PBPC-REQ message is utilized to request the adjustment of assigned MCS for PDL burst. The BS will respond with the PBPC-REP message for either confirming or denying the alternation in the suggested MCS.

3.2 Admission Control Procedure

In the PDC approach, some criteria should be exploited to determine the execution of direct communication between two SSs. A two-tiered admission control scheme for a BS and two attached SSs is presented in this subsection. In wireless communication system, the data transmission range for each station is proportional to its corresponding transmission power. In order to avoid potential interference introduced by adopting the PDC approach, the distance

factor is considered as the first-tiered constraint (\mathcal{C}_1), which is defined as

$$\mathcal{C}_1 : D(SS_s, SS_d) \leq D(SS_s, BS),$$

where $D(x, y)$ denotes the relative distance between x and y ; while the source SS and destination SS of an intra-cell traffic is represented as SS_s and SS_d respectively. In other words, the transmission power utilized by SS_s for achieving direct transmission is adjusted to be equal to or less than that as specified in the conventional IEEE 802.16 mechanism.

On the other hand, for the purpose of enhancing the efficiency for data transmission, channel conditions among the BS and (SS_s, SS_d) pair should be taken into account. Different MCSs associated with various number of data bits are adopted for data transmission under different channel conditions. Based on channel states and the corresponding MCSs, the second-tiered constraint (\mathcal{C}_2) is defined as

$$\mathcal{C}_2 : T_{PDC}(SS_s, SS_d) \geq T_{Conv}(SS_s, SS_d),$$

where $T(SS_s, SS_d)$ represents the raw user throughput defined as "number of bits per second that is received by the destination SS_d while the source is SS_s ". In other words, the raw user throughput resulted from the PDC approach (T_{PDC}) should be at least equal to or higher than that from the conventional IEEE 802.16 mechanism (T_{Conv}). The values of both T_{PDC} and T_{Conv} are derived as the description in the following paragraph.

MCS index	Modulation	Coding rate	Coded block size (byte)	Receiver SNR (dB)
0	BPSK	1/2	24	3.0
1	QPSK	1/2	48	6.0
2	QPSK	3/4	48	8.5
3	16-QAM	1/2	96	11.5
4	16-QAM	3/4	96	15.0
5	64-QAM	2/3	144	19.0
6	64-QAM	3/4	144	21.0

Table 1. OFDM Modulation and Coding Schemes

Table 1 shows the supported MCSs that are specified within the IEEE 802.16 standard. In the considered OFDM system, the raw data rate R_d of a MCS with index ξ is represented as

$$R_d[\xi] = \frac{B_u[\xi]}{T_s}, \quad (1)$$

where T_s is the OFDM symbol duration. The notation $B_u[\xi]$ indicates the number of uncoded bits per OFDM symbol of a MCS with index ξ , which is obtained as

$$B_u[\xi] = N_d \cdot \log_2 M \cdot R_c[\xi], \quad (2)$$

where N_d denotes the number of data subcarriers and $R_c[\xi]$ is the coding rate of a MCS with index ξ . The value of the parameter M depends on the adopted MCS, i.e., $M = 2$ for BPSK, $M = 4$ for QPSK, $M = 16$ for 16-QAM, and $M = 64$ for 64-QAM. Moreover, the OFDM symbol duration T_s can be acquired as

$$T_s = T_b + T_g = T_b + G \cdot T_b = \frac{1 + G}{\Delta f}, \quad (3)$$

where T_b and T_g represent the useful symbol time and the cyclic prefix (CP) time respectively. The notation G denotes the ratio of T_g to T_b . The subcarrier spacing Δf is obtained as

$$\Delta f = \frac{F_s}{N_s} = \frac{8000}{N_s} \cdot \left\lfloor \frac{n \cdot BW}{8000} \right\rfloor, \quad (4)$$

where N_s indicates the number of total subcarriers. The notation F_s represents the sampling frequency with its value specified by the IEEE 802.16 standard as in (4), where n is the sampling factor and BW is the channel bandwidth. By substituting (4) into (3), the OFDM symbol time can be approximated as

$$T_s = \frac{N_s}{F_s} \cdot (1 + G) \approx \frac{N_s}{n \cdot BW} \cdot (1 + G). \quad (5)$$

With (2) and (5), the raw data rate R_d of a MCS with index ξ in (1) becomes

$$R_d[\xi] \approx \frac{N_d \cdot \log_2 M \cdot R_c[\xi] \cdot n \cdot BW}{N_s \cdot (1 + G)}. \quad (6)$$

Based on (6), the raw user throughput by adopting the PDC approach is acquired as

$$T_{PDC}(SS_s, SS_d) = R_d[\xi_{(s,d)}], \quad (7)$$

where $\xi_{(s,d)}$ represents the index of a MCS that will be assigned to the direct link of the (SS_s, SS_d) pair. On the other hand, the raw user throughput in the conventional IEEE 802.16 mechanism is constrained by the two-hop transmission, i.e., from SS_s to BS and from BS to SS_d . Thus the T_{Conv} can be obtained as

$$T_{Conv}(SS_s, SS_d) = \frac{1}{2} R_d[\phi_{(s,d)}], \quad (8)$$

where

$$\phi_{(s,d)} = \min \left[\xi_{(s,BS)}, \xi_{(BS,d)} \right]. \quad (9)$$

The notation $\xi_{(s,BS)}$ denotes the index of the MSC utilized in the link between the SS_s and BS; while that is assigned to the link between the BS and SS_d is represented as $\xi_{(BS,d)}$.

3.3 Direct Communication Procedures

Based on the aforementioned management structures and admission control scheme, the direct communication procedures of the PDC approach are explained in this subsection. Considering a basic IEEE 802.16 PMP network that consists of a BS and two SSs, an intra-cell traffic flow is existed between the SSs. Two transport connections are established for packet transmission, i.e., a UL transport connection from the source station SS_s to the BS and a DL transport connection from the BS to the destination station SS_d . The initialization of direct communication is achieved by conducting the link request and information collection. The source-destination pair (SS_s, SS_d) anticipating to establish the direct link are required to provide their location information and channel conditions to the BS. The collected information is utilized in the admission control scheme mentioned above.

Fig. 4 illustrates an exemplified message flows of the SS-initiated procedure for direct communication. In the case that SS_s intends to conduct direct communication with SS_d , it attaches a PDL subheader to a data packet that will be delivered to the BS; meanwhile, the location

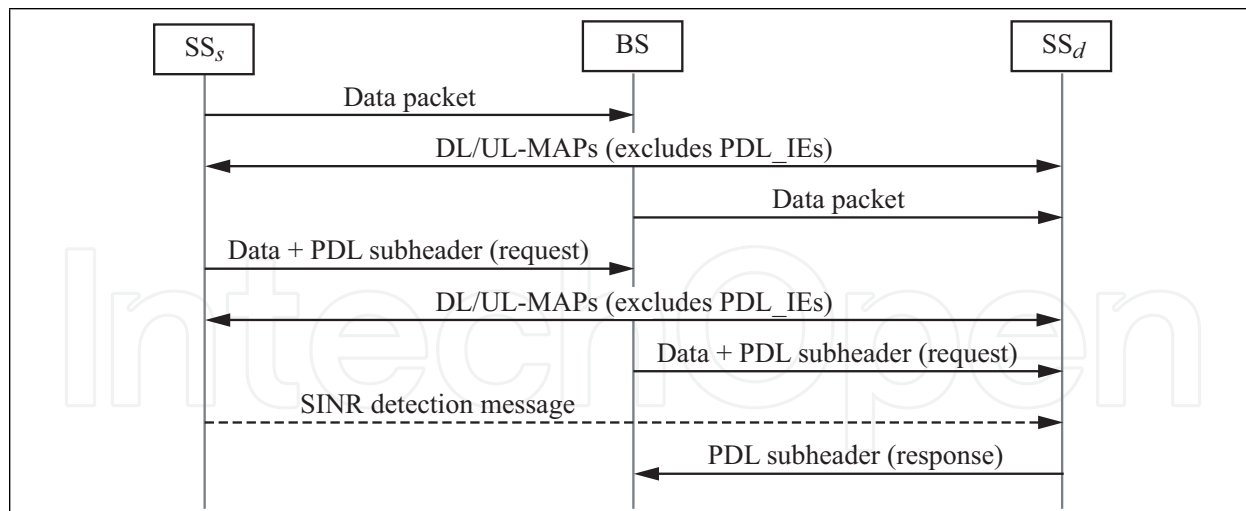


Fig. 4. Schematic diagram of SS-initiated procedure for direct communication.

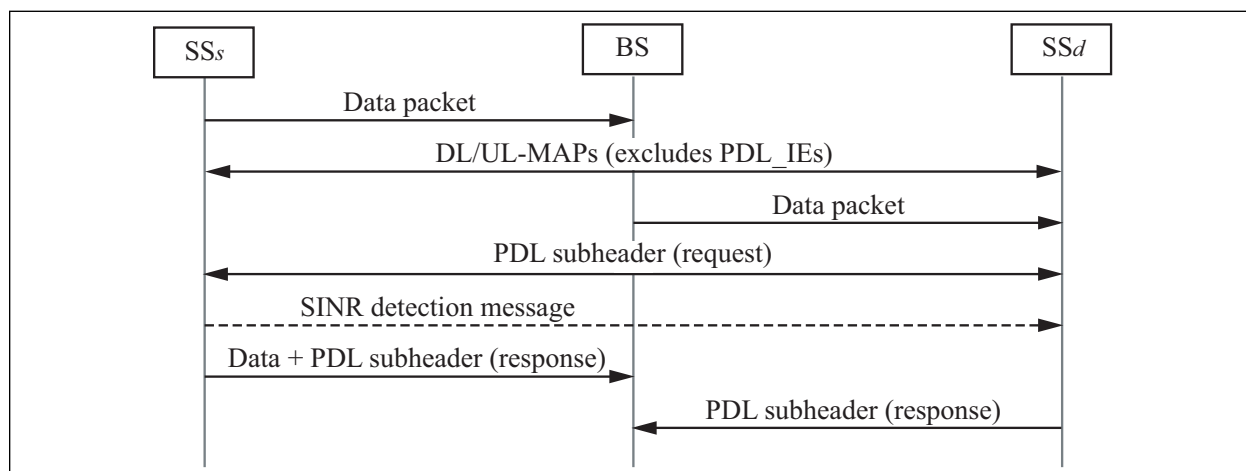


Fig. 5. Schematic diagram of BS-initiated procedure for direct communication.

information of SS_s will be filled into the PDL subheader. As the BS receives the request PDL subheader from the SS_s , the BS will attach a PDL subheader to the data packet and conduct the transmission to SS_d . Moreover, the BS will arrange a DL burst for SS_s with the assignment in the corresponding DL-MAP message. SS_s will transmit an SINR detection message to SS_d with the BPSK-1/2 MCS for estimating the channel state of the direct link. After receiving the PDL subheader and the SINR detection message from the BS and SS_s respectively, SS_d will transmit a response PDL subheader associated with the calculated SINR value. It is noted that the location information of SS_d is carried in the response PDL subheader if it is required by the BS. On the other hand, the BS-initiated direct communication procedure is shown in Fig. 5. Contrary to the SS-initiated procedure, the BS actively announces the link request along with the PDL subheader to the specific SS_s , i.e., SS_s and SS_d . As SS_s receives the requesting PDL subheader from the BS, it will utilize the response PDL subheader to provide the location information that is requested by the BS. The remaining steps of the BS-initiated procedure are similar to that of the SS-initiated case, such as the SINR detection and SS_d response. The BS executes the admission control procedure after it received the response PDL subheader transmitted from SS_d . Based on the collected information, the aforementioned two-tiered con-

trol scheme is exploited by the BS to either confirm or deny the direct communication request between SS_s and SS_d . If the request is rejected, the BS will broadcast a denying announcement along with the PDL subheader. On the other hand, a confirming announcement will be transmitted if the request is granted. Consequently, the BS will arrange the PDL bursts for the direct link in the subsequent frames.

After receiving the confirmation announcement, the considered SSs will activate the procedure of direct communication. According to the received MAPs associated with the PDL IEs, SS_s will conduct packet transmission directly to SS_d within the PDL bursts. Moreover, SS_d will continuously observe and evaluate the channel condition for the direct link with the adaptation to an appropriate MCS. The calculated SINR is compared with the receiver SNR range of the current MCS (as listed in Table 1) by SS_d . If the existing MCS is observed to be improper for the current channel condition, SS_d will initiate a PBPC-REQ message to the BS for suggesting an appropriate MCS. Consequently, the BS will respond a PBPC-REP message with a recommended MCS.

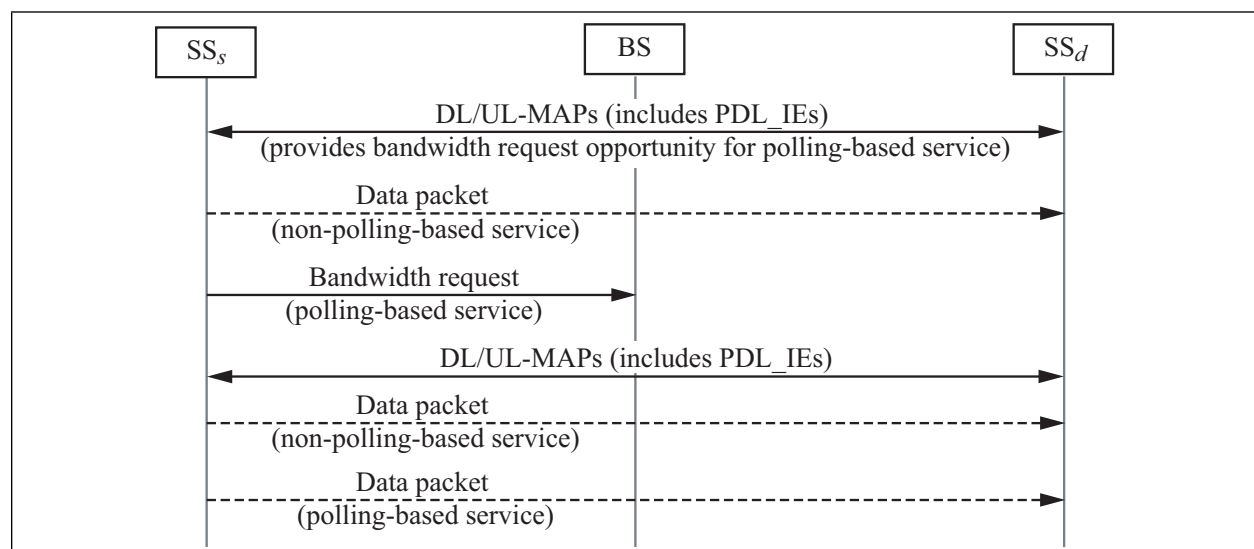


Fig. 6. Schematic diagram of bandwidth request procedure in PDC approach.

It is worthwhile to mention that bandwidth requests are conducted by an SS based on individual transport connection; while bandwidth grants from the BS is executed according to the accumulated requests from the SS. In other words, the bandwidth grant is addressed to the Basic CID of the corresponding SS, not to the individual transport CIDs. As a result, the CID specified for the PDL burst becomes the Basic CID of SS_s . Furthermore, in order to integrate with the existing specification, the procedures of bandwidth requests and allocations specified in the IEEE 802.16 standard are implemented within the proposed PDC approach. Fig. 6 illustrates the bandwidth request procedure while the PDC approach is adopted. It can be observed that the BS preserves the PDL burst for non-polling based service periodically. Furthermore, the BS will continue to provide unicast bandwidth request opportunity for the polling-based services based on the original transport CIDs of SS_s . The unicast bandwidth grant of those services will consequently be assigned to the PDL burst based on the Basic CID of SS_s .

The procedure for the link termination occurs as one of the following two conditions is satisfied: (i) the channel condition of the direct link is becoming worse than that from the indirect channels (i.e., via the BS); (ii) the direct communication is determined to be ceased. It is noted

that the link termination can be initiated by either the BS or SS. In the SS-initiated termination procedure, the SS will transmit a termination PDL subheader to the BS. As the message is received by the BS, it will broadcast an announcement along with a PDL subheader to both SS_s and SS_d regarding the termination of the direct link. On the other hand, for the BS-initiated termination procedure, the termination information is actively announced by the BS. As a result, the BS and the associated SSs will return to adopt the original packet transmission mechanism as defined in the IEEE 802.16 standard.

4. Performance Evaluation

The performance of the proposed PDC approach is evaluated and compared with the conventional packet transmission mechanism in IEEE 802.16 PMP networks via simulations. A single BS with 12 SSs uniformly distributed within the BS's coverage are considered as the simulation layout. The OFDM modulation and coding schemes listed in Table 1 are adopted in the simulation. The occurring frequencies for both inter-cell traffic and intra-cell traffic are considered uniformly distributed. The packet lengths are selected to follow the exponential distribution; while the Poisson distribution is adopted for packets arrival time. Since scheduling algorithm is not specified in the IEEE 802.16 standard, the direct round robin (DRR) (Shreedhar & Varghese, 1996) and weighted round robin (WRR) (Katevenis et al., 1991) algorithms are selected as the BS's DL and UL schedulers respectively. The DRR algorithm is also utilized by the SS to share the UL grants that are provided by the BS among their connections. The parameters adopted in the simulations are listed in Table 2.

Parameter	Value
Channel bandwidth (BW)	7 MHz
Number of total subcarriers (N_s)	256
Number of data subcarriers (N_d)	192
Sampling factor (n)	8/7
Sampling frequency (F_s)	8 MHz
Useful symbol time (T_b)	32 μ s
CP time (T_g)	2 μ s
The ratio of CP time and useful time (G)	1/16
OFDM symbol duration (T_s)	34 μ s
Maps modulation	BPSK
Data modulation	QPSK, 16-QAM, 64-QAM
Frame duration	5 ms, 10 ms
SSTTG/SSRTG	35 μ s
Initial ranging interval	5 OFDM symbols
Bandwidth request interval	5 OFDM symbols
Average packet size	200 bytes
Simulation time	1 sec

Table 2. Simulation Parameters

Fig. 7 shows the comparison of the user throughput with an increasing number of intra-cell traffic flows ranging from 10 to 100 (frame duration = 5 and 10 ms). As can be expected that the user throughput increases as the number of intra-cell traffic flows is augmented. It can be observed that the proposed PDC approach outperforms the conventional IEEE 802.16 scheme

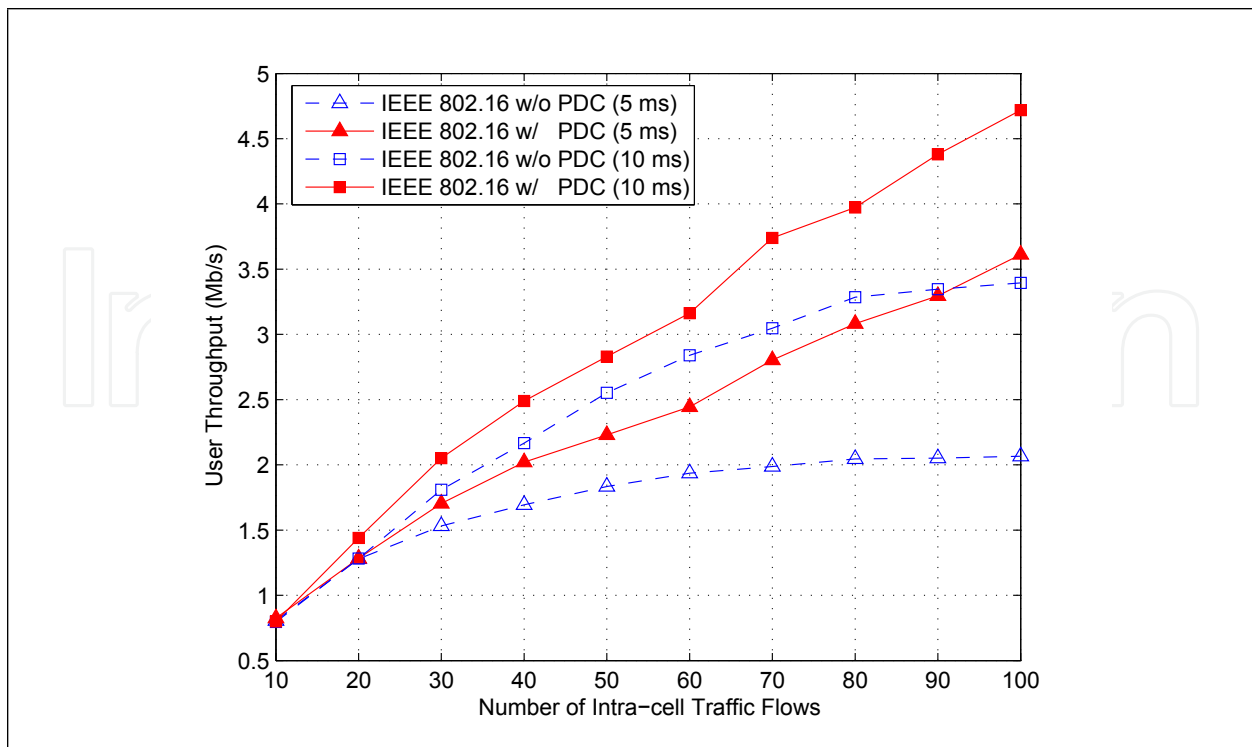


Fig. 7. Performance comparison: user throughput versus number of intra-cell traffic flows.

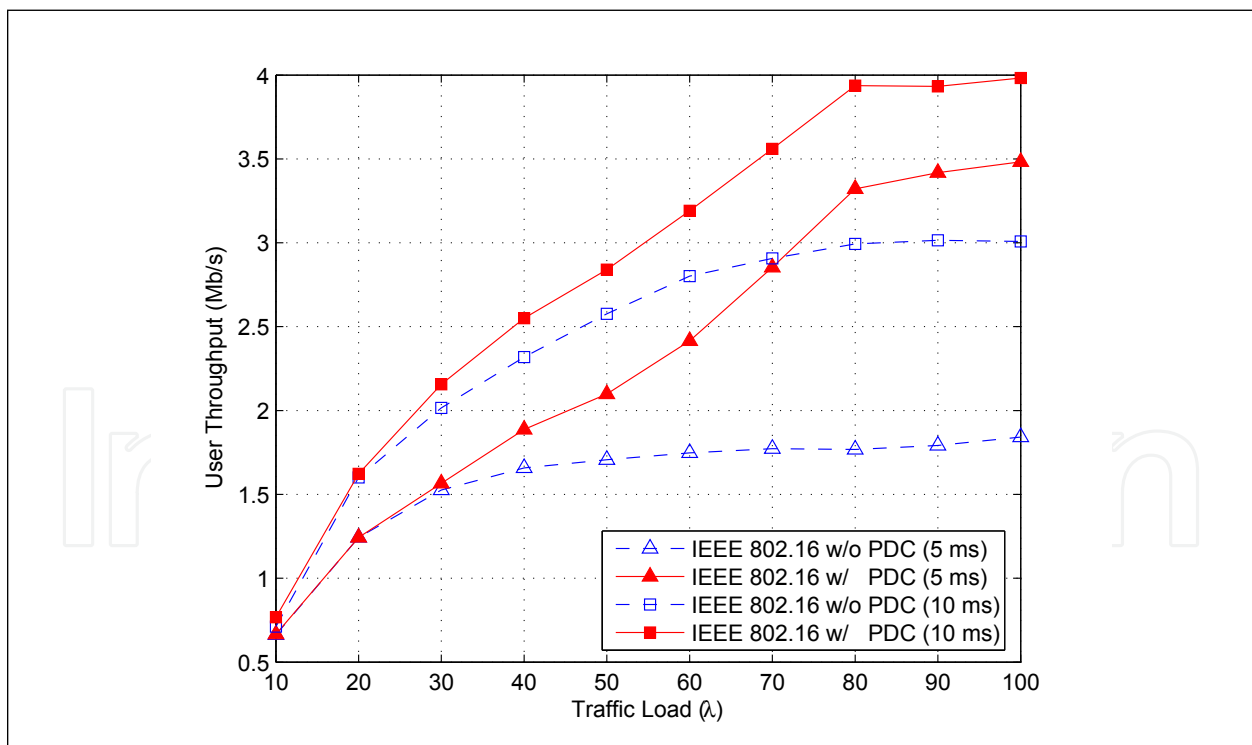


Fig. 8. Performance comparison: user throughput versus traffic load.

with higher user throughput under different frame durations. In the conventional mechanism, it is required for the intra-cell traffic to be forwarded by the BS. Consequently, more than twice

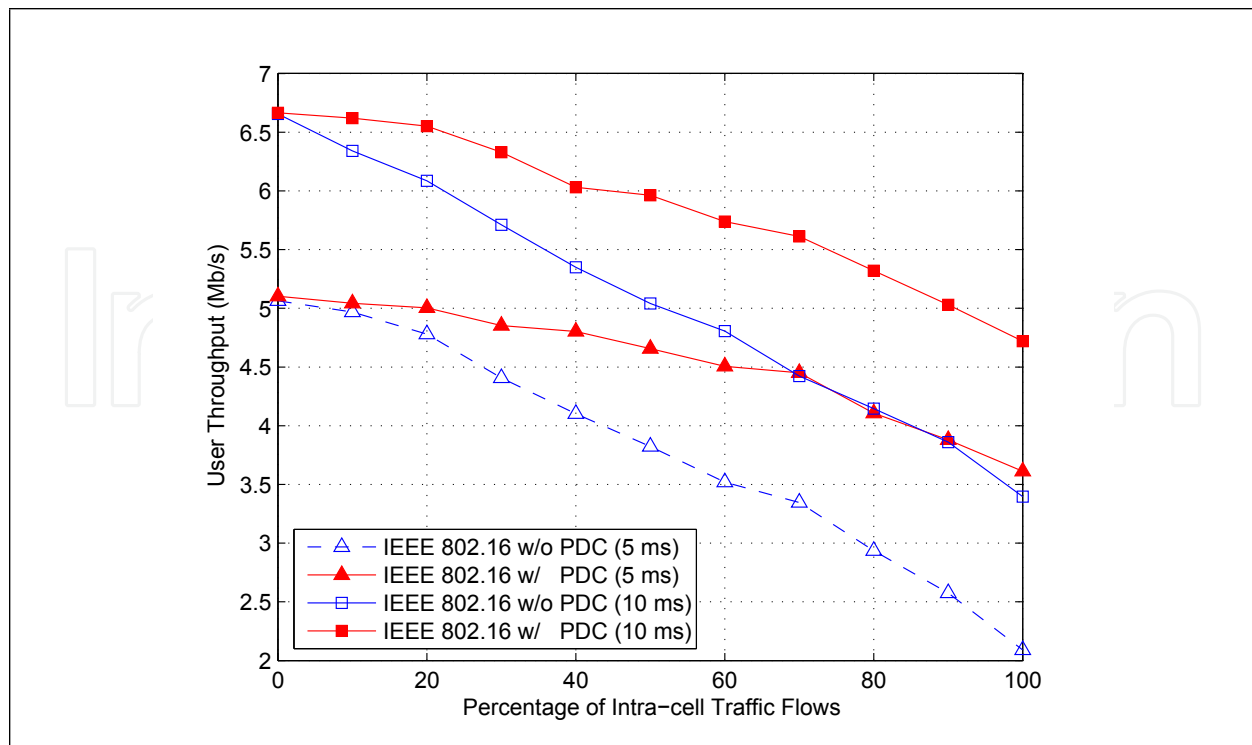


Fig. 9. Performance comparison: user throughput versus percentage of intra-cell traffic flows.

of the communication bandwidth is necessitate for the packet transmission. By adopting the proposed PDC approach, the intra-cell traffic can be directly transmitted from the source station to the destination station, which resulted in saved bandwidth. Moreover, the longer frame duration can achieve higher user throughput owing to the reason that less control overheads are required within the transmission. The comparison of the user throughput under different traffic load (λ) is illustrated in Fig. 8, wherein there are 50 intra-cell traffic flows. Similar performance benefits can be observed by adopting the proposed PDC approach.

In order to evaluate the influence from the inter-cell traffic, the user throughput with an increasing number of inter-cell traffic flows ranging from 10 to 100 is shown in Fig. 9 (with the number of total traffic flows is equal to 100). It is noticed that the inter-cell traffic can be considered as a particular type of direct communication within the cell since the packets are passed from the BS to SS directly. Consequently, the user throughput is decreased as the percentage of the intra-cell traffic is augmented since there are increasing amounts of indirect links within the network. Nevertheless, the PDC approach can still provide comparably higher user throughput under different percentages of intra-cell traffic flows. The merits of the proposed PDC scheme can be observed.

5. Conclusions

In this book chapter, a flexible and contention-free point-to-point direct communication (PDC) approach is proposed to achieve direct transmission between SSs within IEEE 802.16 PMP networks. With the considerations of both relative locations and channel conditions among the BS and SSs, a two-tiered admission control scheme is proposed to determine the establishment of direct link between the SSs in the PDC approach. While adapting the PDC approach, the

BS arranges specific time intervals for the two SSs that are actively involved in direct transmission. The advantage of exploiting the PDC approach is that both the required bandwidth for packet transmission and packet-rerouting delay for intra-cell traffic can be significantly reduced. Furthermore, the design of the PDC approach is compatible and can be directly integrated with the existing protocols defined in the IEEE 802.16 standard. The effectiveness of the proposed PDC approach can be observed via the simulation results, which demonstrate that the PDC approach outperforms the conventional IEEE 802.16 transmission mechanism in terms of user throughput.

6. Acknowledgments

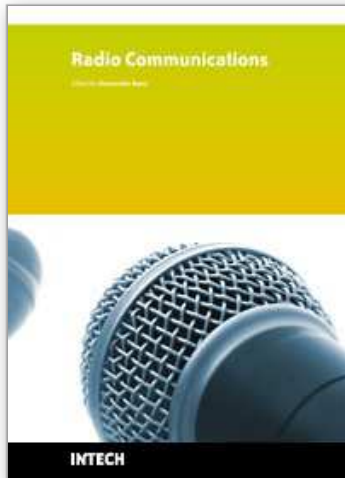
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InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

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